

Scheduling of real-time traffic in IEEE 802.11 networks

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Abstract

Real-time applications require the provision of time-bounded services from the network, however, the scheduling algorithms used in wired networks are not suitable for wireless networks because they assume that the channel is error free. Besides, the scheduler has only a limited knowledge of the arrival processes of the uplink traffic. In this paper, we propose scheduling algorithms for the transport of real-time traffic in IEEE 802.11 wireless LANs which deal with channel errors. We also present the simulation results obtained with these algorithms.

Keywords: scheduling, real-time, error correction, IEEE 802.11.

1 Introduction

Wireless networks present many advantages over their wired counterparts. The freedom from cables reduces costs with infrastructure, allows a quicker installation and increases the mobility. On the other side, these networks are subject to higher and more variable error rates.

In order to provide quality of service (QoS) guarantees to its connections, a wireless network normally requires the presence of a central controller, usually located in a base station (BS) or access point (AP), which is responsible for the scheduling of the transmissions made by all stations in the cell. For the transport of real-time traffic, the scheduler tries to assure that the packets are delivered before a specified deadline is reached.

Many scheduling algorithms have been proposed in the literature for use in wired networks, such as the Weighted Fair Queueing (WFQ), suitable for handling asynchronous traffic, and the Earliest Due Date (EDD), for time-bounded traffic [1]. However, these scheduling algorithms are not appropriate for wireless networks because they assume that the channel is error free. Moreover, the access

point does not know when a packet arrives to the queue of a remote station, so it cannot rely on the packet tagging mechanisms used by conventional algorithms. A practical implementation of a scheduling algorithm should address these issues, as well as some characteristics of the wireless network, such as its medium access control (MAC) and error control (EC) functions.

Many papers that deal with scheduling in wireless networks considering the channel errors have been published recently [2] [3], but their main concern is the fair sharing of the available bandwidth among asynchronous traffic flows. The transport of real-time traffic (voice) in IEEE 802.11 networks is considered both in [4] and [5]. However, the former assumes an error free channel, while the later does not consider the retransmission of lost frames.

We presented results concerning the scheduling of real-time together with asynchronous traffic in HIPERLAN/2 (High Performance Radio Local Area Network) networks in another paper [6]. In this paper, we propose scheduling algorithms for the transport of real-time traffic in IEEE 802.11 [7] networks. These algorithms are tailored to the particularities of these networks and deal with channel errors and retransmissions.

The next section presents a brief overview of the IEEE 802.11, focusing on the access method conceived for the transport of real-time traffic. Section 3 describes the proposed scheduling algorithms, while section 4 presents simulation results obtained with these algorithms. Finally, the conclusions are presented on section 5.

2 Overview of IEEE 802.11

The IEEE 802.11 standards define several physical layer options, which allow a network to operate either in the infrared, 2.4 GHz or 5 GHz band.

The fundamental access method of IEEE 802.11, called Distributed Coordination Function (DCF)¹, is a contention-based random access protocol more appropriate to the transport of asynchronous traffic. In order to provide support to time-bounded traffic, an optional method called Point Coordination Function (PCF) is also defined.

The PCF is a polling protocol which works under the coordination of the access point (AP). The AP defines a periodic superframe composed by a Contention Free Period (CFP), where the PCF is used, followed by a Contention Period (CP), where the DCF is used, as show on Figure 1.

After the nominal start of the superframe, the AP waits for the channel to be idle for a PCF InterFrame Space (PIFS) period in order to start a new CFP, which begins with the transmission of a Beacon frame by the AP. During the CFP, the AP polls the stations present in the polling list according to the order and periodicity defined by the scheduling mechanism. The destination station responds to the poll

¹ For a description of the DCF function, please refer to the standard [7].

frame with a data frame. The AP ends the CFP with the transmission of a CF-End frame, either when the polling procedure is done for the superframe or when the value defined for the CFP maximum duration parameter is achieved. The transmissions during the CFP are spaced by Short InterFrame Space (SIFS) periods.

During the PCF, the acknowledgement (ACK) of a frame received without errors is piggybacked in the next frame². The frame containing the ACK, which is transmitted on the opposite direction, can be either a poll, response or CF-End frame.

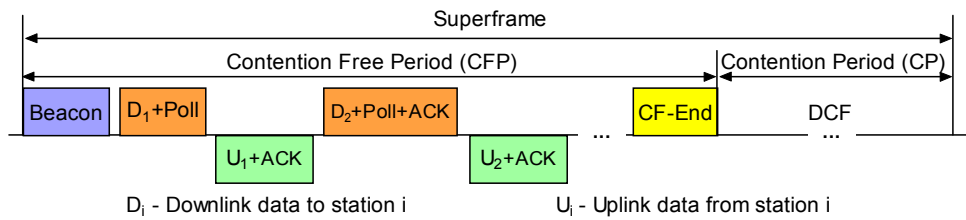


Figure 1: Superframe structure and PCF access procedure.

When a DCF transmission initiated during the CP of a superframe goes beyond the nominal start of the next superframe, the beginning of the CFP is delayed because the AP has to wait until the channel becomes idle in order to start the CFP. Besides, the CFP maximum duration is referenced to the nominal start of the superframe, so the CFP is shortened. This effect is known as stretching. A DCF transmission can begin immediately before the nominal start of a new superframe, so the stretching can extend up to the time it takes to transmit a maximum size MPDU (MAC Protocol Data Unit).

3 Scheduling Algorithms

This section presents two scheduling algorithms for use with IEEE 802.11 networks. They were conceived to provide a fast recover of data frames corrupted due to channel errors. In the absence of errors, the following rules apply for both algorithms:

- The stations in the polling list are polled sequentially.
- Each station is polled once on each superframe.

In the first algorithm, the retransmission of corrupted data is made in the next superframe at the same position in the sequence. Figure 2 shows an example that describes the use of this algorithm. The behavior for two stations (named 1 and 2)

² Regardless of the its destination address.

is highlighted. In the absence of errors, a station responds to the polling frame by sending the data received from the upper layers since the previous time it was polled (as show for the station 2). When the data frame was corrupted in the previous superframe (station 1, superframe $i-1$), it is retransmitted on the current superframe, so the data that was supposed to be transmitted in this superframe is transmitted only in the next one, together with the respective data.

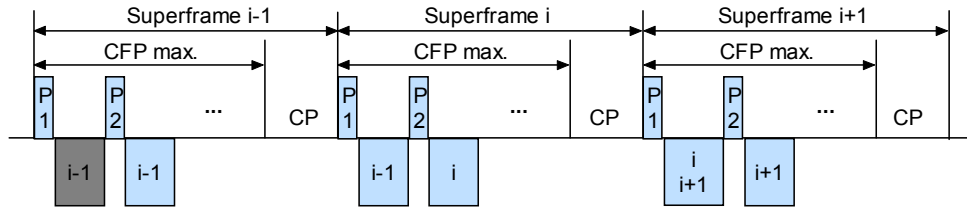


Figure 2: Example of the behavior of the first algorithm proposed

In the second algorithm, when the access point receives a corrupted message, it puts the station address at the end of a retransmission list. After all the stations have been polled by the access point, it starts to poll the stations belonging to the retransmission list. Figure 3 presents an example of the use of this algorithm where the transmissions of stations 1 and 3 during the regular polling cycle are corrupted. After polling the last station on the polling list (station n), the access point polls the station 1, but the message is corrupted for the second time, so the station address is put on the retransmission list again. Then, the access point polls successfully the station 3 for the second time and the station 1 for the third time. After that, the retransmission list becomes empty, so the access point transmits a CF-End frame to finish the contention free period (CFP). If the CFP maximum duration is reached during the retransmission phase, the retransmission list is emptied and the corrupted data has to be transmitted on the next superframe during the regular polling cycle, the same way it is done in the first algorithm.

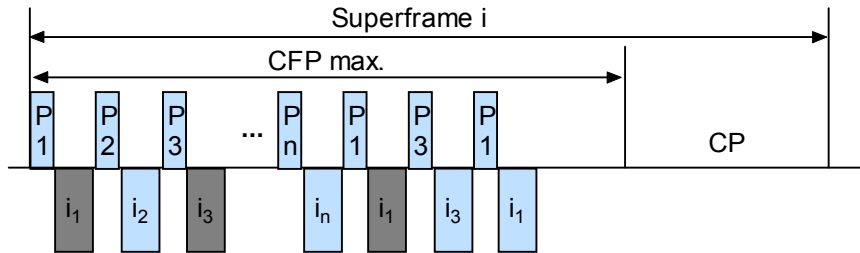


Figure 3: Example of the behavior of the second algorithm proposed

4 Simulation Results

In order to evaluate the performance of the proposed algorithms, we developed a detailed model of the IEEE 802.11 network based on its standards. This model was implemented using OMNET++ [8], an open-source discrete event simulation software. Results were obtained from steady-state simulations.

The simulations used the parameters relative to the version “a” of the network, known as IEEE 802.11a [9], which operates in the 5 GHz band using Orthogonal Frequency Division Multiplexing (OFDM) and allows bit rates ranging from 6 Mbit/s to 54 Mbit/s.

The evaluation scenario consists of 30 terminals which transmit data to an access point. Each terminal generates CBR (Constant Bit Rate) traffic relative to one ATM (Asynchronous Transfer Mode) connection at 70.67 kbit/s, which corresponds to a cell interarrival time of 6 ms. The MPDU payload is formed by concatenating the ATM cells waiting in the transmitter queue. The application envisioned with this scenario is to provide wireless access to an ATM based data acquisition and control system [10].

Table 1 presents the values of the configurable parameters of the network that were used in the simulations. For the fixed parameters, please refer to the standards.

Table 1: Parameters of IEEE 802.11a

Transmission rate	18 Mbit/s
Superframe duration	6 ms
CFP maximum duration	5 ms

In order to minimize the jitter, the superframe duration of IEEE 802.11a was made equal to the cell interarrival time (6 ms). Thus, when the channel is error free, the terminals send a MPDU containing a single cell each time they are polled.

First results are relative to a scenario with no errors on the channel. Figure 4 shows the delay distribution for 3 out of the 30 connections. The delay suffered by the cells of a particular connection is practically constant. The cells from different connections were generated arbitrarily at the same time, beginning at $t = 0$, so the delays presented on the figure increase according to the polling sequence. In a more general case, the delay value will depend on the difference between the MPDU transmission time and the cell arrival time, but will always be smaller than the cell interarrival time.

The channel utilization associated to these 30 connections is high (64.7 %) because of the high overhead of the IEEE 802.11 protocol, namely when the payload length is small. The efficiency can be increased using a larger superframe, but the delay and jitter will be larger as well.

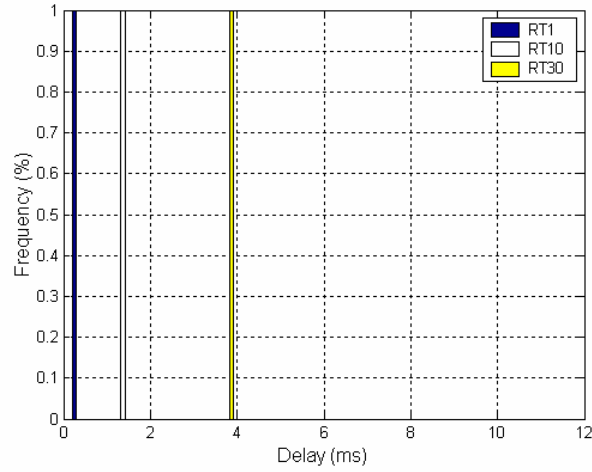


Figure 4: Delay distribution for IEEE 802.11a with no errors

The following results are based on the previous scenario, this time with the introduction of channel errors. A bit error rate (BER) of 10^{-4} respective to the MAC layer was used. Results are shown only for the connection of the first terminal (RT1) because the other connections present similar results. Figure 5 shows the delay distribution using the first scheduling algorithm, while Figure 6 presents the results obtained with the second algorithm. The overall channel utilization are 65.6 % and 69.3 %, respectively, which means a increase of 1.4 % and 7.1 % with respect to the error-free scenario.

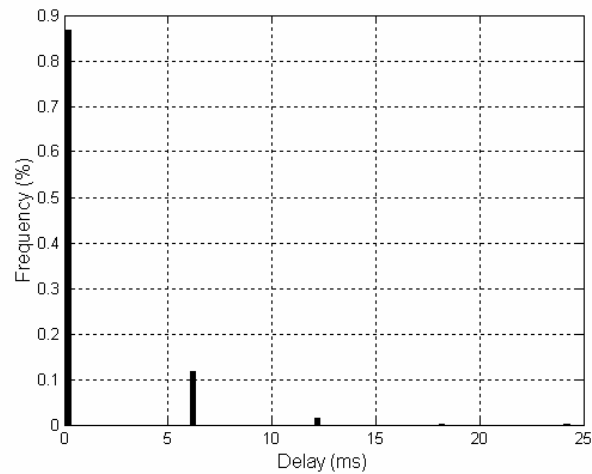


Figure 5: Delay distribution of RT1 connection with BER = 10^{-4} (first algorithm)

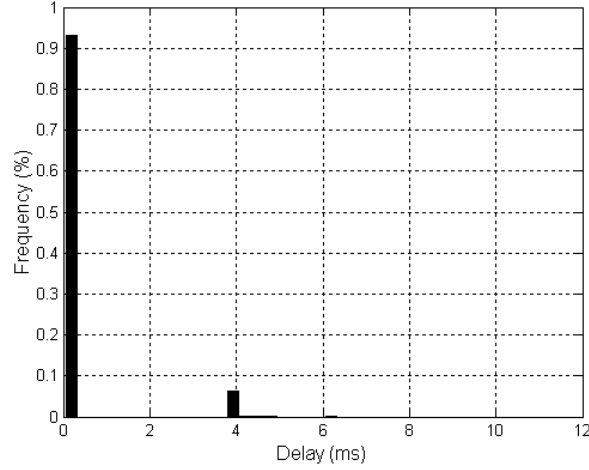


Figure 6: Delay distribution of RT1 connection with BER = 10^{-4} (second algorithm)

The second algorithm presents a much smaller delay variation, which compensates the moderately higher channel utilization. Most of the cells are retransmitted on the same superframe where they were initially transmitted, although a few cells have to be retransmitted in the following superframe because the maximum size of the CFP is reached.

5 Conclusions

In this paper, we proposed scheduling algorithms for the transport of real-time traffic in IEEE 802.11 networks. The delay performance obtained with the second algorithm was much better and show that, in the presence of moderate levels of error, lost frames can be quickly recovered using retransmission, with the requirement of only a small percentage of extra bandwidth.

The throughput efficiency achieved with the proposed scenario was low due to the high overhead introduced by the IEEE 802.11 MAC protocol for the transport of small packets. In this respect, the HIPERLAN/2 network is a better alternative according to our results.

The packet error rate (PER) can be reduced with the use of a more robust (lower bit rate) PHY mode, thus we conceived an adaptive mechanism for deal with burst errors. We also implemented a model of the DCF function on the simulator, which allows the evaluation of the performance of the system with a combination of real-time and asynchronous traffic. We expect to publish the outcome of these works

soon, as well as a comparison between the IEEE 802.11 and the HIPERLAN/2 systems.

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